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Consideration of the Effect of Miscellaneous Factors on Frost Resistance of High Strength Concrete by Using the Factorial Design Method

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Abstract

Factorial design method is applied to investigate the effects of various factors simultaneously rather than to conduct a series of single-factor experiment.

As the results, frost resistance of the concrete specimens, in both W/C ratio of 0.28 and 0.35, was highly affected by the type of coarse aggregate that is, andesite produced more durable concrete than the limestone. Durability factor of the specimens, with W/C ratio of 0.28, which were demolded after 1 day and transferred to the curing room was higher than those demolded after 2 days. This stated the efficiency of the high early curing in high strength concrete.

Keywords : miscellaneous factors, frost resistance, high strength concrete, factorial design method

1. Introduction

It is evident that frost resistance of concrete is influenced by many factors such as properties of materials, method of casting and curing and interaction of these factors.[1-4] To study the frost resistance of concrete, an investigator could attempt to vary only one factor at a time, and this procedure is not always desirable or practical when the number of factors and levels for the factors increases. To overcome this difficulty, factorial design method is effective in investigating the effects of various factors simultaneously rather than conducting a series of single-factor experiment.[5)]

2. Factorial design method

The interpretation of the results of factorial experiment depends upon the statistical variance ratio test of significance (analysis of variance). The statistical variance ratio F_A for the factor A is

$$F_A = (S_A/\phi_A)/(S_C/\phi_e) = V_A/V_C \qquad (1)$$

Where S, ϕ and V are the sums of squares, the degree of freedom, and the mean square sums, respectively, and the suffix A and C represent factor A and error source, respectively.

If F_A is less than 100-α% point of the F distribution that is, $F_A<F(100-\alpha\%)$, the effect of factor A on the experimental results is not significant. However, If F_A exceeds the 100-α% point of the F distribution, the effect of the factor A is judged to be significant. F-values for the 5% and 1% right tail points are used from the table of Snedecor.

When there exists a significant factor, the confidence interval(confidence limit) C_L and the factor effects ρ are calculated by using Taguchi's formula(1)

$$C_L = \pm\sqrt{\frac{F(\phi_A, \phi_e, \alpha)V_e}{ne}} \qquad (2)$$

$$\rho = \frac{S_A - \phi_A V_e}{S_T} \qquad (3)$$

where n_e is the number of repetition times of the experiment, and S_T is total sum of squares. The variance ratio of the interaction between the two factors of A and B is also measured by using F_{AB} and $F(\phi_{AB}, \phi_e, \alpha)$

$$F_{AB}=(S_{AB}/\phi_{AB})/(S_e/\phi_e) \qquad (4)$$

$$\phi_{AB}=(\phi_A-1)(\phi_B-1) \qquad (5)$$

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Using two series of specimens with W/C ratios of 0.28 and 0.35, 16 units of experiments were conducted for twelve factors each at two levels. The factors which were considered to affect the frost resistance of concrete and the code factors are as follows:

1) mixer capacity(A),
2) type of coarse aggregate (B),
3) surface condition of coarse aggregate (C),
4) surface condition of fine aggregate (D),
5) type of mixer (E),
6) mixing time (F),
7) mixing procedure (G),
8) mixing temperature (H),
9) type of mold (I),
10) compacting method (J),
11) removal age (K),
12) testing machine (L).

Furthermore, three interaction factors among the factors of G, E and G, F and F, E were considered. The factors and the levels used for every factor are given in Table 1. Basically 16 units of experiment were carried out (L16), the corresponding orthogonal arrays of the factorial design (L16) are given in Table 2.

Table 1 Factor codes and level of factors

Factors	Factor code	Level of the factors	
		1	2
Mixer capacity	A	55(lit)	75
Coarse agg.	B	Limestone	Andesite
Surface	Coarse agg.	Saturated	Dry
Condition of :	Fine agg.	Saturated	Dry
mixer type (Axes direction)	E	Vertical	Horizontal
Mixing time	F	(2min)	4
Mixing method (Mixing material)	G	At the same Time	In the order
Mixing temp.	H	10℃	30℃
Type of mold in : (Compressive test)	I	Disposable	Ordinary
Compact method	J	JIS A 1132	Vibrator table
Removal age	K	1(day)	2
Testing machine	L	100 Tons	200

Table 2 L16, factorial design

Test Series	G	B	H	F	G F	C	J	A	L	I	F E	K	D	G E	E
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	·1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

3. Experimental procedure

3.1 Materials

Ordinary portland cement and two types of aggregates of andesite and limestone were used in the mixture as shown in Table 3. The natural river sand was used as a fine aggregate. The physical properties of coarse and fine aggregates are given in Table 4.

The water content was applied equally as 170 kg/m^3 for all concrete mixtures. The superplasticizer and air-entrained agent were used to achieve the desired slump value(i.e. 200 $\pm$20 mm) and predetermined air content.

3.2 Testing procedure

Slump and air content of the fresh concrete were determined and the additional tests that were also carried out are as follows:

1) freeze thaw test in accordance with the ASTM C666-A,
2) compressive strength,
3) modulus of elasticity.

Table 3 Physical properties of aggregates

Aggregate	Specific gravity		Absorption
	Saturated surface dried	Oven dried	Water
Sand	2.68	2.63	2.04
Andesite	2.65	2.57	3.00
Limestone	2.69	2.67	0.93

Table 4 Mix proportions of concretes

W/C (%)	S/A (%)	Cement kg/m^3 (l/m^3)	Water kg/m^3 (l/m^3)	Coarse Agg. kg/m^3 (l/m^3)	Fine Agg. kg/m^3 (l/m^3)	Add. Cement (%)
35	43.5	486(154)	170	966(359)	737(277)	1.7
35	43.5	486(154)	170	966(359)	737(277)	1.7
28	41.0	607(192)	170	936(353)	652(245)	2.2
28	41.0	607(192)	170	950(353)	652(245)	2.2

4. Results of analysis variances

4.1 Freeze thaw test

For both W/C ratios, the durability factors and air content of all the 16 series are shown in Fig. 1 and 2. For both non-air-entrained and air-entrained concrete, deterioration occurred, for instance, the specimens made by 0.35 W/C ratio and 6.2% air content(i.e. series 2)were deteriorated, while the non-air-entrained specimens of series 8 had a durability factor equal to 100. However, the results declare that besides the air content, there are many factors which affect frost durability of high strength concrete severely.

The analysis of variance for freeze thaw test of both W/C ratios specimens was given in Table. In the case of the specimens made by 0.28 W/C ratio, removal age, mixing temperature and coarse aggregate are highly significant factors and affect the result (at 1% level), and the affecting factors are 33.6, 18.6 and 14.8% respectively (Table 5). Analysis of variance of the results of the specimens with 0.35 W/C ratio indicate that type of coarse aggregate, surface condition of fine aggregate, mixing temperature,

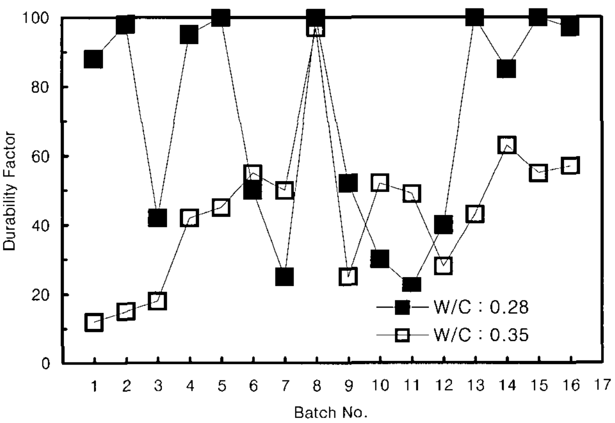

Fig. 1 Durability factors versus series of experiments

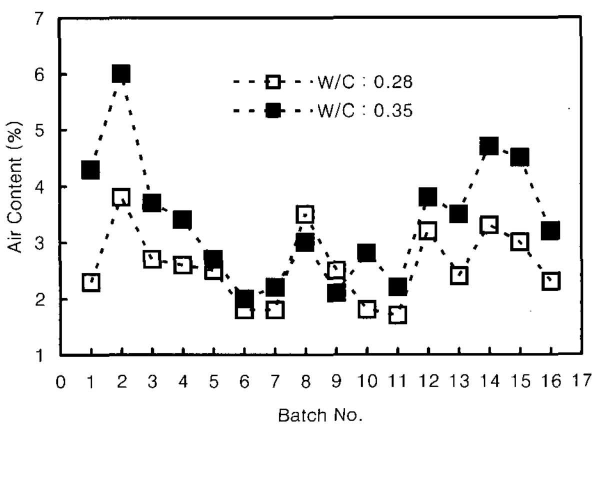

Fig. 2 Air content versus series of experiments

and mixer capacity are highly significant factor and affect the results at 1% significant value. The interaction of mixing method and mixing time also affect the results at 5% level. The results of the freeze thaw tests of specimens with 0.35 W/C ratios show that it was also highly affected by coarse aggregate and the factors effect was 44.6%.

The average value of the durability factors for both W/C ratios against significant factors is shown in Fig. 3 and 4. The confidence interval is also shown in these figures. It is shown that for W/C ratio of 0.28, the specimens which were removed after 24 hours, had higher durability factor than those which were removed after 2 days. This can be attributed to the high efficiency effect of early curing for low W/C ratio specimens. Fig. 3 also shows the effect of low and high mixing temperature (10℃ and 30℃); as it is shown the low mixing temperature produces a high durable concrete with W/C ratio equal to 0.28. However in the specimens with 0.35 W/C ratio, high mixing temperature leads to higher durability factor. Surface condition of the fine aggregate and mixer capacity are also significant factors (1% level) and mixing time, the interaction effect of mixing time and mixing method are the other factors which affect the results at 5% level.

The results of the freeze thaw tests of specimens with 0.35 W/C ratios show that it was also highly affected by coarse aggregate and the factor effect was 44.6%.

The average value of the durability factors for both W/C ratios against significant factors is shown in Fig. 3 and 4.

Table 5 Analysis of variance of durability factor(W/C : 0.28)

Factor code	Degree of freedom	Mean sum of squares	Variance ratio F	Percentage of factor effect
A	-	228.75		
B	1	2350	11.13*	14.8
C	-	212.4		
D	1	755		
E	1	738		
F	-	4.9		
G	-	381		
H	1	5066	24*	33.6
I	-	156		
J	-	2.14		
K	1	2897	13.73*	18.6
L	1	738		
G*F	-	295		
F*E	-	31		
G*E	-	191		
Error	9	211		33
Total		14450		100

* Significant at 1% level.

The confidence interval is also shown in these figures. It is shown that for W/C ratio of 0.28, the specimens which were removed after 24 hours, had higher durability factor than those which were removed after 2 days. This can be attributed to the high efficiency effect of early curing for low W/C ratio specimens. Fig. 3 also shows the effect of low and high mixing temperature (10℃ and 30℃); as it is shown the low mixing temperature produces a high durable concrete with W/C ratio equal to 0.28, however, in the specimens with 0.35 W/C ratio, high mixing temperature leads to higher durability factor. Surface condition of the fine aggregate and mixer capacity are also significant factors (1% level), mixing time, the interaction effect of mixing time and mixing method are the other factors which affect the results at 5% level. The results of analysis of variance by taking it into account the effect of W/C ratio indicated that at 1% level, type of coarse aggregate and W/C ratio are significant factors at 1% level which are shown in Fig. 5 (a and b).

The factors which affect the results at 5% level are shown in Fig. 6. It can be seen that the factor of mixing temperature, removal age, surface condition of fine aggregate and the interaction factor of mixing time and mixing method are the factors which affect the results at 5% level. From this Fig. 5, it is evident that the type of coarse aggregate highly affects the durability of concrete irrespective of W/C ratio.

The an-alysis of variance indicated that the affecting factor of coarse aggregate was 25.2%, while it was 13.2% for W/C ratio factor. A low mixing temperature and also removal at 1 day benefits frost durability of concrete mixtures

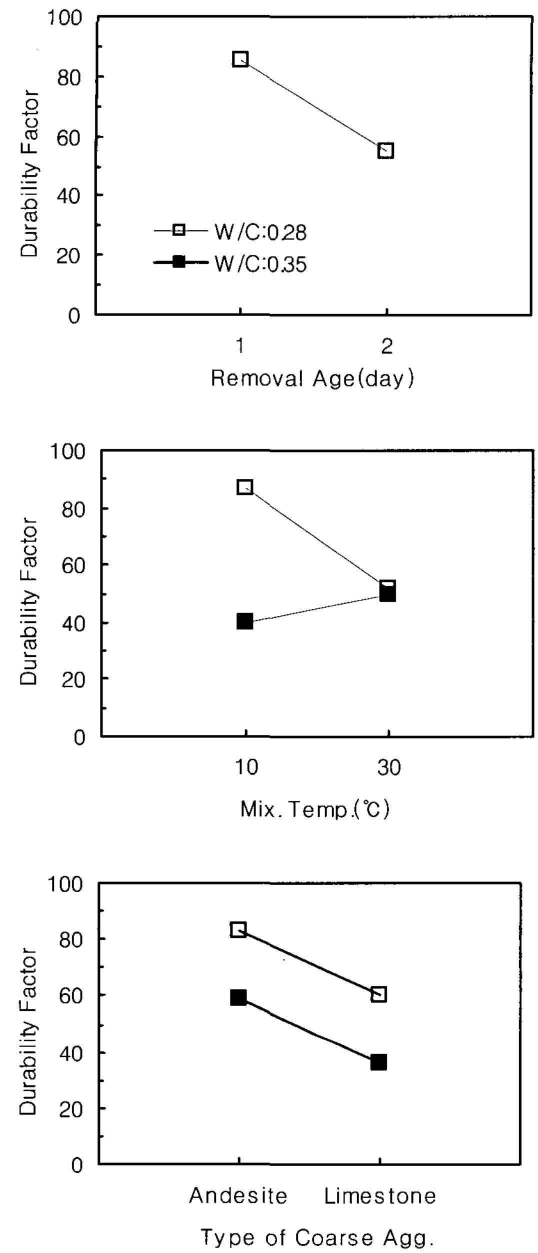

Fig. 3 Effect of significant factors of removal age, mixing temperature and type coarse aggregate on average of durability factor (W/C ; 0.28, 0.35)

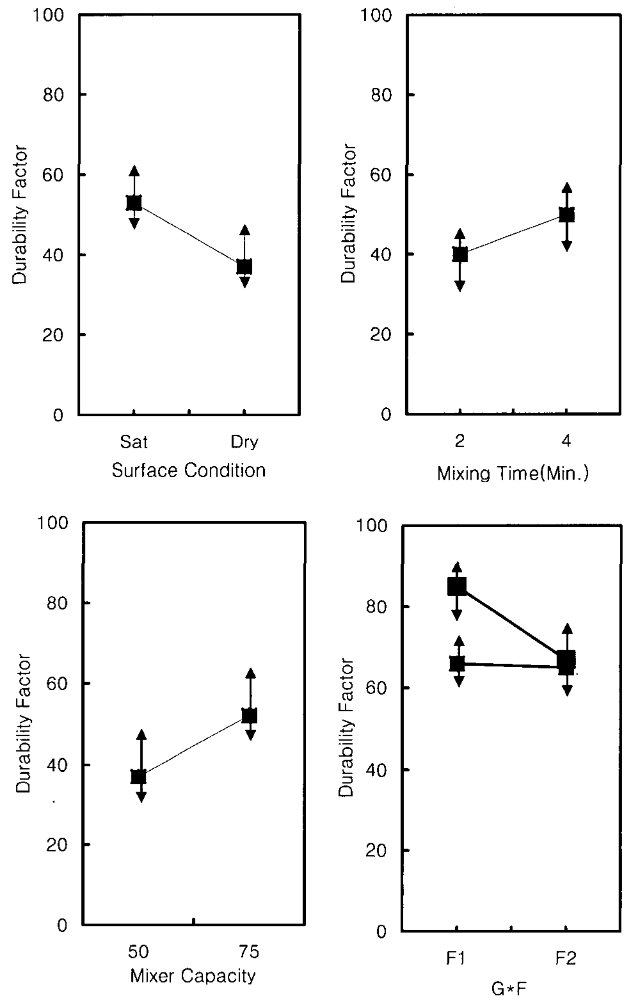

Fig. 4 Effect of significant factors of surface condition of fine aggregate, mixing time, mixer capacity and interaction of (mix time & mix method) on average durability factor of concrete

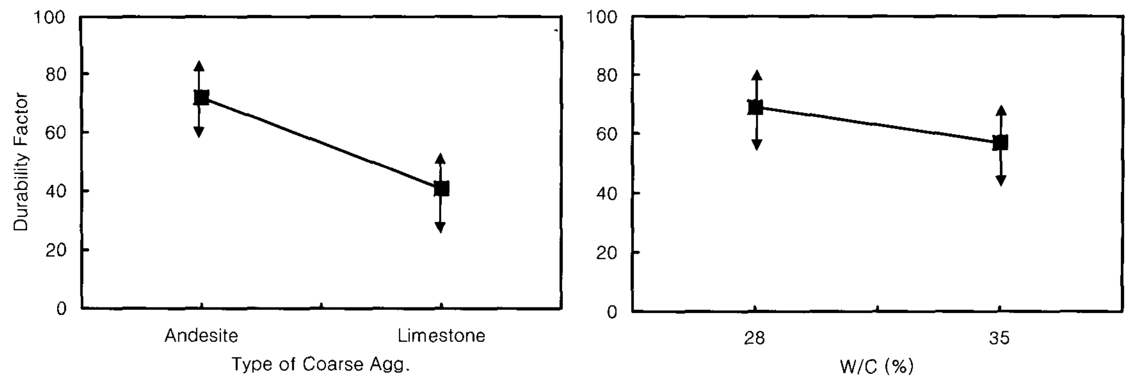

Fig. 5 Effect of significant factors of : a)type of coarse aggregate and b)W/C ratio on average durability factor

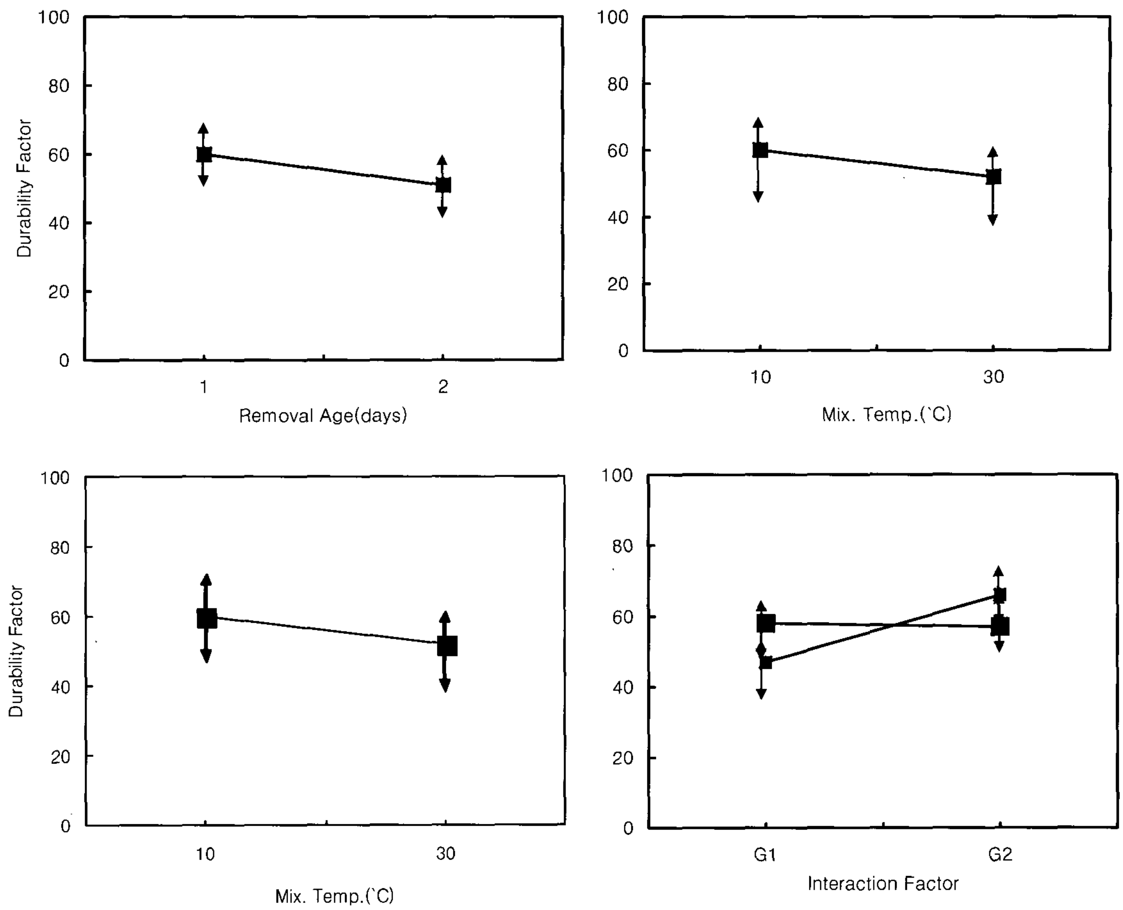

Fig. 6 The effect of significant factors of : a)removal age, b)mix temperature, c) surface condition of fine aggregate, and d)interaction factor of (mix time and mix method) on average durability factor

4.2 Compressive strength

The result of analysis of variances of compressive strength at 4 weeks which W/C was also taken into account, indicated that the W/C ratio was the highest significant factor and its effect was 61.42%. Type of coarse aggregate also affects the compressive strength of concrete specimens as well as frost durability and the affecting factor were 10.8%. Furthermore, compressive strength versus significant factors (at 1% level) are shown in Fig. 7(a, b, c and d). It can be seen from the Fig. 7(a, b and c) that mixing time and compaction method was the factors which influenced compressive strength. The capacity of testing machine was another factor which affected the result of compressive strength of specimens.

4.3 Modulus of elasticity

The results of analysis of variance for secant modulus of elasticity at 4 weeks are shown in Fig. 8. As shown, the

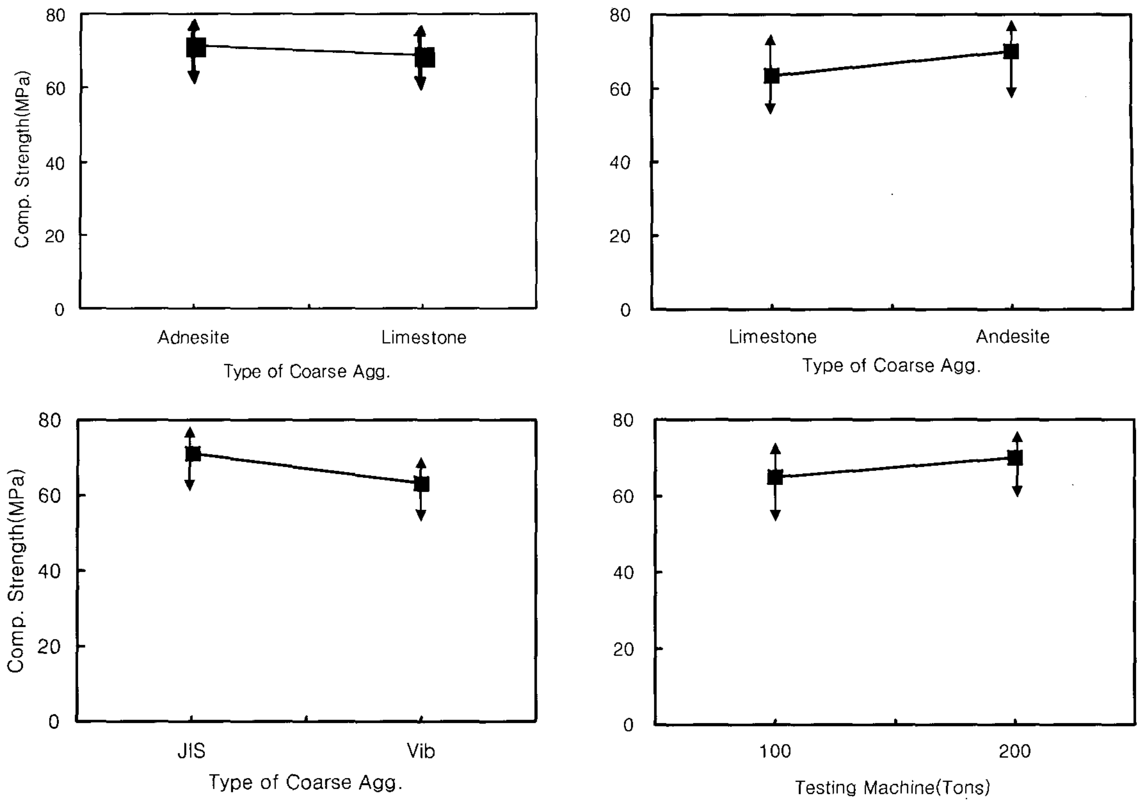

Fig. 7 Effect of significant factors of : a)type of coarse aggregate, b)mixing time, c) compact method, and d)testing machine on average durability factor

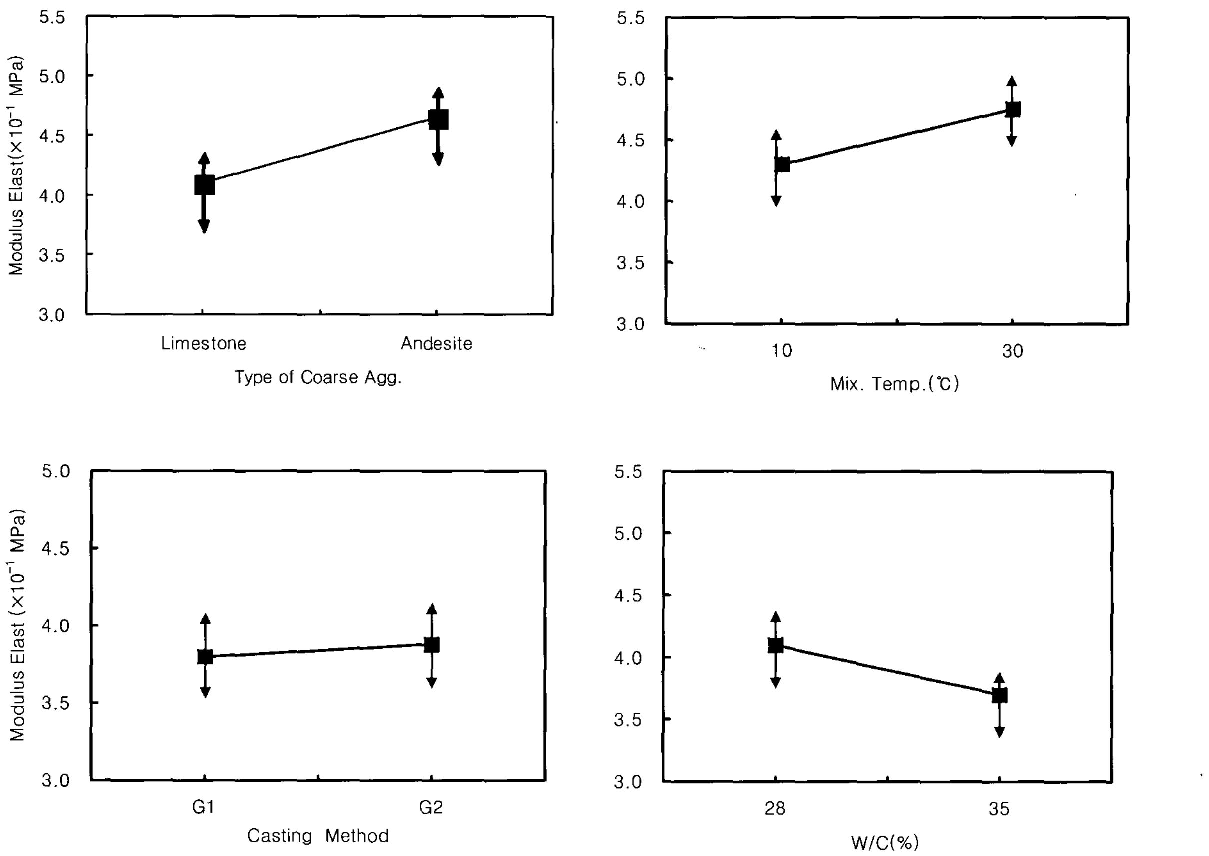

Fig. 8 Effect of significant factors of : a)type of coarse aggregate, b)mixing time, c) casting method, and d)W/C ratio on average durability factor

Table 6 Affecting ratio of coarse aggregate and W/C ratio on frost resistance and strength properties

Concrete property	Coarse agg.	W/C
Frost resistance	25.2	13.5
Compressive strength	10.7	61.4
Modulus	59.4	16.8

factors which influenced the results at 1% were type of coarse aggregate, W/C ratio, mixing temperature, and compact method. It is interesting to note that the type of coarse aggregate influenced the results more strongly than W/C ratio. Limestone produced concrete with a higher secant modulus than andesite. Using high mixing temperature (30℃) and vibration table lead to the concrete with high modulus of elasticity.

Consequently, the effect of coarse aggregate and W/C ratio on the frost resistance and also strength properties of high strength concrete which were obtained by factorial design method are summarized in Table 6. The results indicated that the effect of coarse aggregate on frost resistance and modulus of elasticity is 2 and 4 times more than W/C ratio. However, W/C ratio has a vital effect on the results of compressive strength

5. Conclusions

Based on the analysis of variance, the following conclusions can be drawn :

1) Frost resistance of the concrete specimens, in both W/C ratio of 0.28 and 0.35, was highly affected by the type of coarse aggregate.
2) Andesite produced more durable concrete than the limestone.
3) Durability factor of the specimens, with W/C ratio of 0.28, which was demolded after 1 day and transferred to the curing room, was higher than those demolded after 2 days. This stated the efficiency of the high early curing in high strength concrete.
4) Casting temperature was a factor which affects the frost resistance of the concrete.
5) As expected compressive strength was influenced more strongly by W/C ratio than the other factors.
6) Modulus of elasticity was highly affected by the type of coarse aggregate. Limestone produced concrete with high modulus of elasticity than andesite.

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